Anokiwave

mmW Solutions. Enabling a new world

All-Silicon Active Antennas for High Performance and low-cost mmWave Systems

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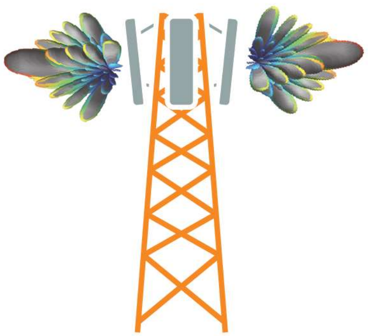
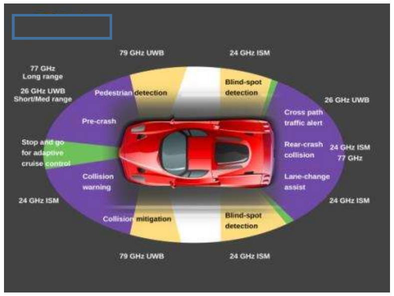
Several major markets for mmWave systems



5G

SATCOM



RADAR

- High power gNodeB
- Fixed wireless access
- Backhaul, Fronthaul, Repeater
- Small cell access point
- Indoor/outdoor CPE
- Mobile devices

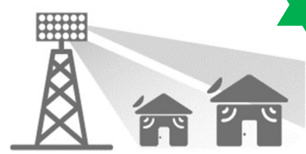
- Ku Band terminal
- Ka Band terminal
- Airborne arrays
- Marine terminal
- Remote area internet access

- Collision avoidance, detection
- Pedestrian detection
- Obstacle detection
- 24GHz, 77GHz

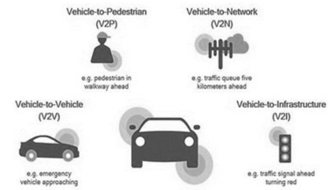
Blossom of 5G Uses Cases demands a Scalable Architecture Anokiwave well positioned with 3 Generation of mmW IC's

High Power Base Stations

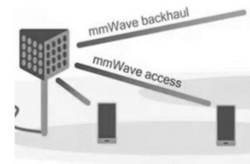
Fixed Wireless Access



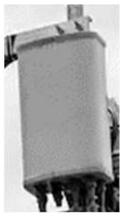
Embedded Vehicle, V2X



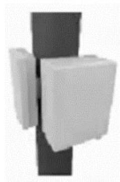
mmWave Integrated Access & Backhaul



Medium Power Microcells



Outdoor CPE, Repeater



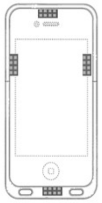
Access Points, Indoor CPE

Embedded Laptop

Embedded Tablet

Hotspot Device

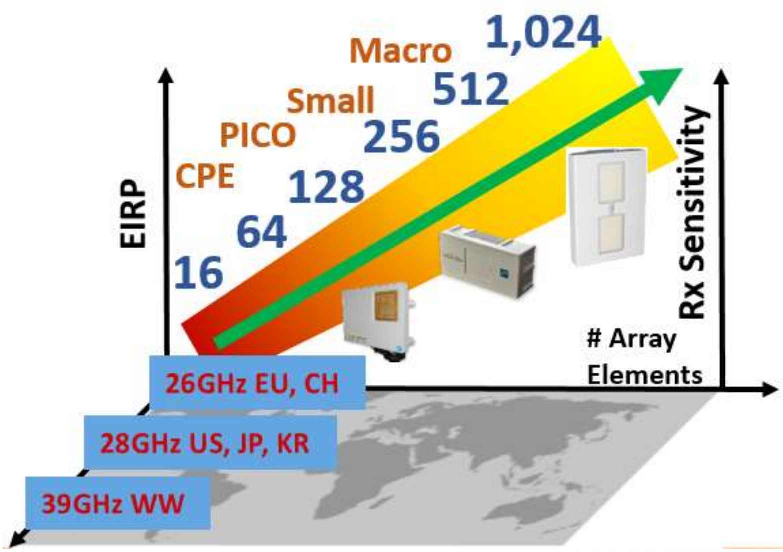
Mobile Phone



M2M IoT Device

*US is moving ahead with mmWave, 24GHz Spectrum auction is ongoing

Si BFIC to cover ALL popular 5G mmW Bands



Anokiwave covers all 5G bands

2020
Features being defined

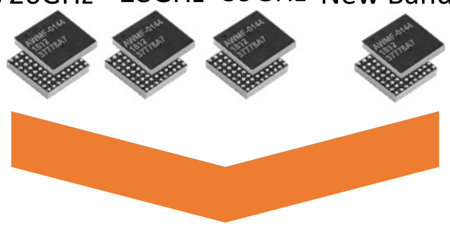
2019
24/28/39 ICs supporting 8Tx, 8Rx channels
IFIC paired with BFIC

2018
24/26, 28, 39GHz quad ICs with **more linear power, lower cost silicon**

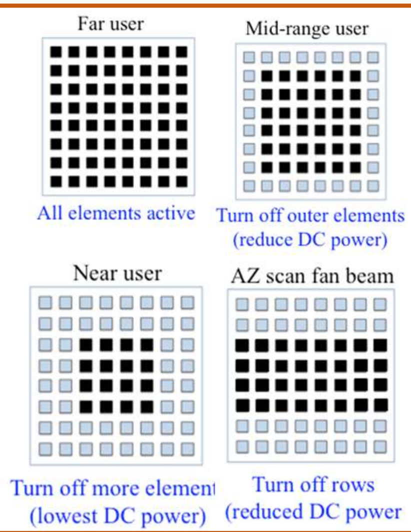
2016
World's **first 28GHz, 39GHz silicon quad** IC for 5G markets

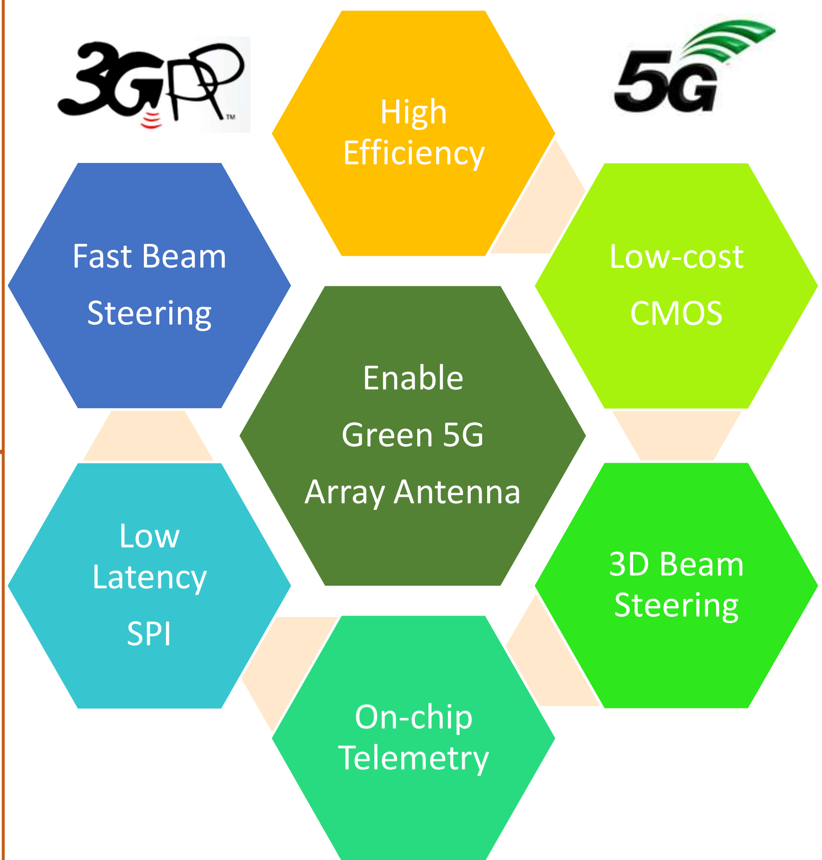
Rich features, functions, easy implementation and lowest cost

24/26GHz 28GHz 39GHz New Band



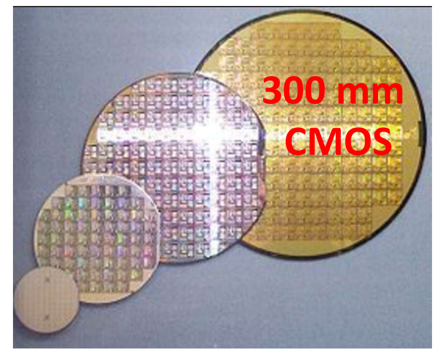
Same SPI Interface
Same PIN out
Same IC Size
One SW Control Package

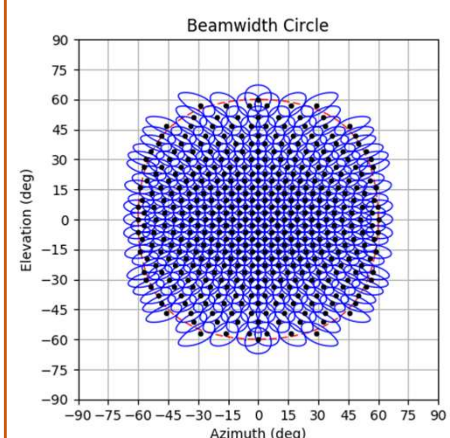




Broadest BFIC Portfolio

The larger Wafer, the lower Cost





Two critical factors for commercializing 5G mmWave

Technical Factors

- Link budget (EIRP, EIS, …)
- Power dissipation
- System size* and weight
- 3GPP Standards

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- High $\frac{EIRP\ (W)}{Pdiss\ (W)}$ ratio
- Low ACLR, EVM
- Low noise figure
- Transient performance
- On-chip telemetry

All-Silicon mmWave antennas address both factors well

Economic Factors

- System development cost
- Operator's Capex
- Ongoing Opex
- Supply chain diversity

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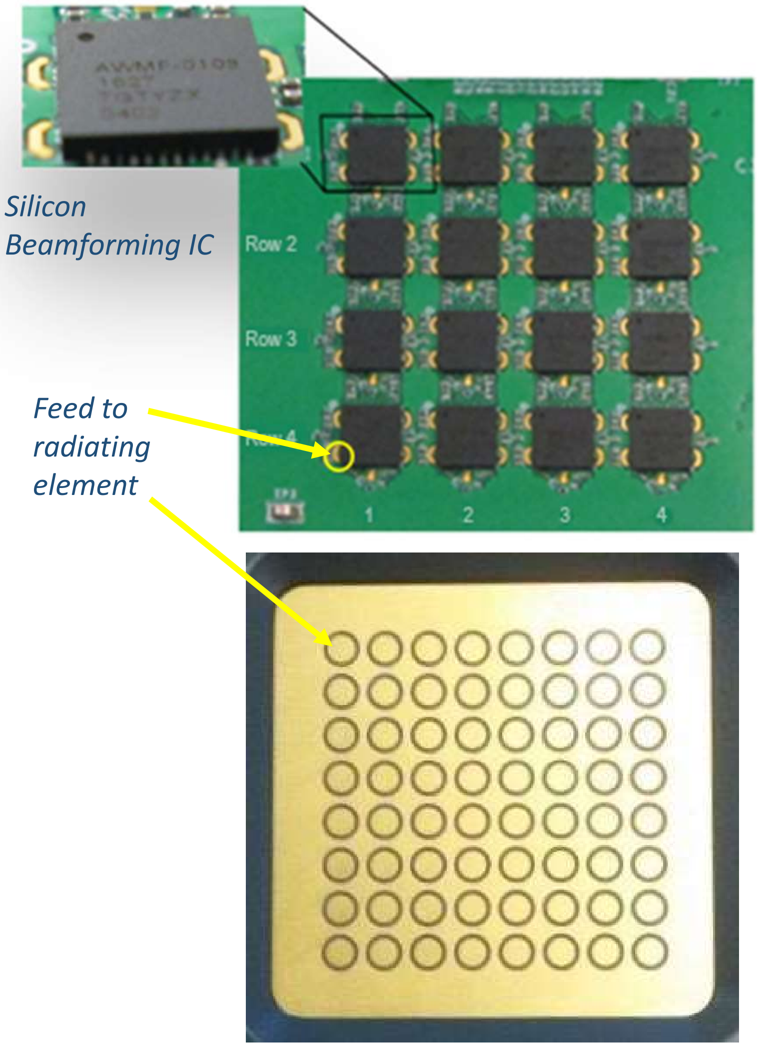
- Planar arrays
- Low cost silicon wafers
- Low prime power
- Minimal array calibration
- Remote monitoring
- Eco-system of array manufacturers

*Size is key issue for Regulatory Approval at local Government level

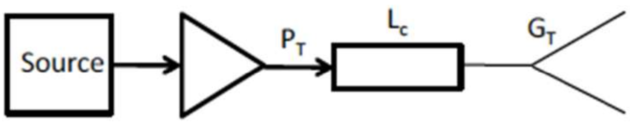
All-Silicon Array Architecture



- Low cost, high volume Si wafer fabrication
- Wideband high linearity and low noise RF performance
- Single positive supply operation
- Highly integrated, small size RFIC
- Multiple RF channels per IC – 4X, 8X BFIC
- IC size enables 2D beam steering in AZ and EL
- Lowest feed loss gives optimum Tx power efficiency and Rx NF
- Combines analog and digital circuits (SoC)

EIRP vs. Conducted Power

The FCC defines EIRP as the sum of three logarithmic terms:



$$EIRP = P_T + G_T - L_C$$

* Path loss after signal amplification (TR switch + Transmission Line + Antenna Feed) wastes power *at the most valuable point in the system*

* Excess power dissipated in the interconnect loss is converted to thermal energy (bad) and requires a larger (more expensive) PSU than required

- Power dissipation/optimization is a holistic assessment of the entire path/system
- Active antenna efficiency/functionality needs to consider *<u>all elements in the signal path AND control path of the sub-array</u>* for an apples-apples comparison
- Non-signal path functions include embedded controllers and the PSU
- This function is normalized to the sub-array level to account for beam-forming architecture (hybrid/analog/digital)

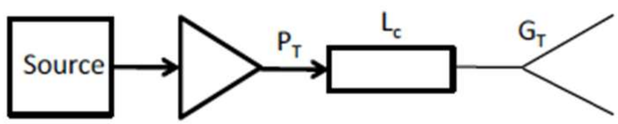
EIRP should be maximized by controlling all three contributing terms:

- Maximizing conducted linear power for lowest power dissipation
- Increasing the available array gain to the maximum allowed by the application
- Minimizing the effect of system losses (which can be dramatic at mmWave)

Thermally Limited System Integration

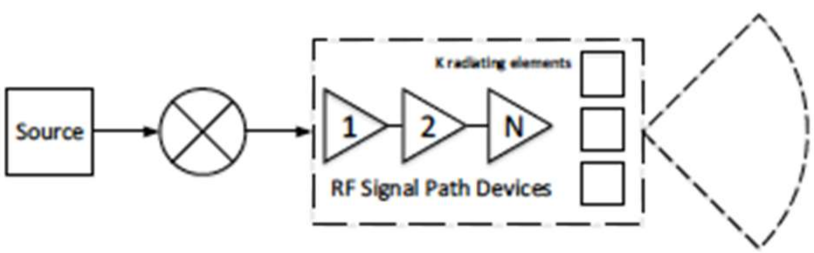
EIRP must be generated
even more efficiently

- Passive antenna replaced by AESA
- Fans and active cooling precluded by reliability concerns

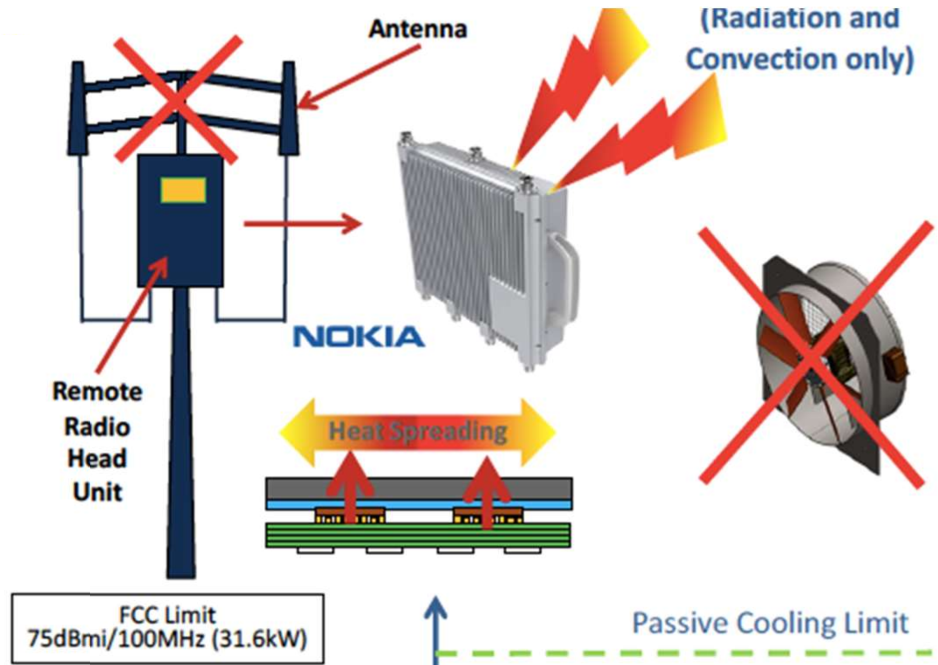


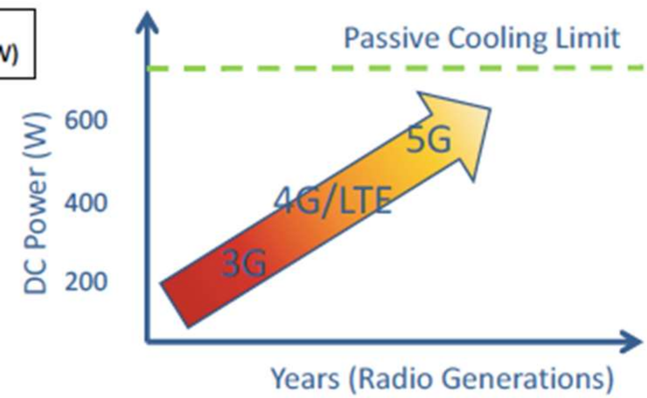
$$EIRP = P_T + G_T - L_C$$

Path loss after signal amplification (TR switch + Transmission line + Antenna feed) wastes power at ***the most valuable point in the system***



Key FoM is ***overall*** Transmitter Efficiency





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Generating efficient, linear TX power at wide channel bandwidths is a critical challenge

- EIRP $\propto$ (No. Elements)^2
- Power dissipation $\propto$ (No. Elements)

  $\therefore$ Larger arrays are better

  Cost and narrow beamwidth limit the size
- Efficiency is set by the **waveform**, <u>independent</u> of device technology (GaAs, GaN, SiGe, CMOS)
- 3% or -30dB EVM using 5G NR 400MHz waveform is a common requirement for OFDM 64QAM waveform
- Linear power is more important than P1dB

Evolution of Modern Communication Systems

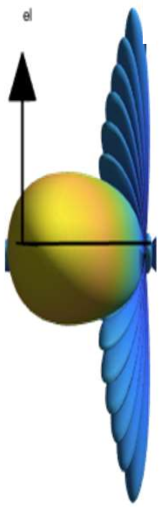
	Standard	Bandwidth MHz	EVM dB	Waveform Modulation
WiFi	802.11b	20	-9	DQPSK
WiFi	802.11g/a	40	-25	OFDM
WiFi	802.11ac wave 1	80	-30	OFDM 256QAM
WiFi	802.11ac wave 2	160	-32	OFDM 256QAM
WiFi	802.11ax	160	-35	OFDM 1024QAM
Cellular	GSM	0.2	-23	GMSK-8PSK
Cellular	WCDMA	3.84	-15	QPSK
Cellular	LTE	20	-22	OFDM
Cellular	LTE-A	40	-27	OFDM
5G	5GTF	800	-30	OFDM 64QAM
5G	5G-NR	1400	-32	OFDM 256QAM

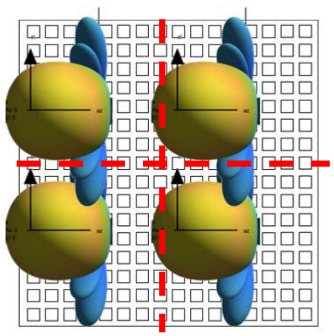
Increasing BW

Decreasing EVM

What level of output power back-off (OBO) is needed to meet the required EVM for low BER?

Reconfigurable 28GHz All-silicon Array





US Trade Compliant Solution (5A991.f)

Enables 4x4 MIMO

Full 2D scan for dense urban environments

Active antenna region

- >1KW EIRP at OP1dB in 256-element mode (~ 65W P_{DISS})
- One 256 element beam or four 64 element beams
- 4x64 arrays for MU-MIMO
- Weather sealed for outside deployment
- Passive thermal management
- 26.4cm x 14.2cm x 6.9cm
- Mass: 3kg
- Embedded controller for simple UI
- Single 12V DC input

Summary

- mmWave silicon core ICs for active antennas are commercially available now
- All-silicon, high efficiency planar arrays are in production today
  - 5G, SATCOM, Automotive Radar markets
- The momentum for increased industrialization is growing quickly
- We are beyond proof-of-concept and academic research
- Silicon provides a clear path to high volume manufacturing and the industrialization required to mass produce efficient, cost effective arrays

Thank You

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